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SUBJECT: Estimate of the Probability and Consequences of Ignition of the HRT Charcoal Beds

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FROM: R. E. Adams and W. E. Browning

Abstract

The ignition temperature of Columbia G activated charcoal in a flowing oxygen stream was determined to be 290°C under conditions simulating the inlet of the HRT charcoal beds. Calculations of charcoal temperatures resulting from beta decay of adsorbed fission gases from the HRT indicate that this temperature will not be reached provided the reactor power does not exceed 10 MW with an accompanying oxygen flow not exceeding 2 liters/min. At lower power levels higher oxygen flow may be tolerated. If, by a combination of circumstances, ignition of the charcoal should occur, it will be possible to extinguish the fire by stopping the oxygen flow. The down-stream propagation of the combustion front is slow enough to allow detection and corrective action to be taken before a serious situation occurs.

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I. Introduction

During operation of the HRT significant quantities of rare gas fission products are produced and removed from the reactor. Disposal of these radioactive gases is accomplished by passing the off-gas stream into two parallel charcoal adsorption beds. The fission product gases are delayed, thus allowing time for decay, in passing through the adsorber system by the process of adsorption and desorption on the surface of the adsorber material. The operating characteristics of this adsorber system have been reported (1).

Radioactive decay of the adsorbed rare gases will heat the activated charcoal. Since the off-gas stream from the reactor is composed mainly of oxygen a potentially unstable situation is created. Combustion of charcoal in an oxygen stream is quite rapid. The design of the HRT charcoal beds provides safety measures which include removal of decay heat by external water cooling and thermocouples to monitor the internal charcoal temperatures resulting from decay of the gaseous fission products (3).

For safe operation the ignition temperature of activated charcoal in a flowing oxygen stream should be known. An ignition temperature of 362°C has been reported for activated charcoal at very low oxygen flow rates (2). Various charcoal manufacturers list ignition temperatures in the 300-400°C range for charcoal in oxygen in systems with very low flow rates. The purpose of this study was to determine the ignition temperature under conditions similar to those present in the HRT charcoal beds and to evaluate the consequence of such ignition.

II. Experimental Study

The first experiment simulated the conditions that might be present in the inlet section of the HRT charcoal beds, with the exception of external water cooling and internal heating by decay of the fission gases.

A charcoal trap was constructed of 5/8 in. O.D. stainless steel tubing. The charcoal occupied 5.75 inches of the tubing and weighed 7.2 grams. Three thermocouples were placed in the charcoal, 1.25, 2.25, and 3.25 inches from the front of the charcoal mass. Because of the manner of heating, ignition was assumed to occur near the inside wall of the tubing and the thermocouples were placed in such a manner to monitor the temperature rise upon ignition in this zone.

An oxygen flow of 250 cc/min was established and the charcoal heated slowly by the tube furnace. Temperatures present in the charcoal were recorded at the front, middle, and end of the mass. Ignition occured at 290°C and the oxygen was allowed to flow into the charcoal until the temperature at the front of the charcoal mass reached 880°C. At this point the oxygen flow was stopped and within 4 minutes the temperature dropped to 430°C. When the temperature reached 370°C the oxygen flow was resumed and a temperature rise to 1020°C was observed. Oxygen flow was stopped and the temperature allowed to drop to 290°C. Upon starting the oxygen flow a rapid rise in temperature occured. After cooling the charcoal to 200°C resumption of oxygen flow did not produce ignition. To check the ignition temperature the bed was heated again with oxygen (250 cc/min) flowing through the charcoal. Ignition again occured at 290°C. A second run was made with oxygen flowing at the rate of 500 cc/min and ignition again occured at 290°C.

The highest internal temperatures were noted to be 1200°C after ignition occurred in this system. Behavior upon stopping oxygen flow was identical to that of the first experiment.

From these experiments it is seen that the rate of combustion of charcoal is controlled by the available oxygen supply. Stoppage of the oxygen flow causes a very rapid reduction in the combustion rate. After ignition has occurred and the oxygen flow is stopped, the temperature of the charcoal must be allowed to fall below the ignition temperature before the oxygen flow can be resumed. The higher ignition temperatures reported in the literature for low flow conditions no doubt result from the accumulation of carbon oxides which dilute the oxygen and raise the ignition point. Under conditions of greater flow these oxidation products are rapidly swept out and a relatively pure oxygen atmosphere is present at the inlet to the charcoal mass. For this reason lower ignition temperatures would be expected.

A second experiment was performed to determine external pipe wall temperature with water cooling while charcoal was burning inside the pipe. The downstream propagation rate of the burning front was also measured. The charcoal was contained in a 5/8 in. O.D. stainless steel pipe suspended under water. Thermocouples were attached to the outside pipe wall down the length of the pipe. Ignition of the charcoal was accomplished by using a small Nichrome heating coil buried at the front of the charcoal mass. A thermocouple was also buried at this point to measure temperatures occurring after ignition. The downstream propagation rate of the burning front was determined by observing the maximum temperature rise as measured by the external thermocouples as the burning front passed the point of attachment. Studies were made at oxygen flow rates of 250, 500, and 1000 cc/min. Results are recorded in the following table.

Oxygen Flow Rate(cc/min)	Max. Internal Temp. (°C)	Max. External Wall Temp.(°C)	Propagation Rate of Combustion Front(cm/min)
250	800	58	0.145
500	900	75	0.391
1000	1060	80	1.11

Neither of these experiments involved radiation conditions or ozone production by beta radiation of the oxygen stream. It is possible that the ignition temperature may be altered somewhat in the actual HRT charcoal beds by these factors. Therefore, to provide a margin of safety, it should be assumed that ignition will occur at a temperature slightly lower than 290°C.

III. Calculated Maximum Charcoal Temperatures of HRT Beds During Reactor Operation

Calculations have been made of the amounts of the various fission gases which will be adsorbed on the charcoal over the length of the HRT beds under equilibrium conditions using the most recent experimental data on adsorption of fission gases. The resulting heat generation and longitudinal temperature profile was then calculated under various conditions of reactor power and total oxygen flow. The method of calculation will be covered fully in a forthcoming report. Briefly, the method consists of dividing the charcoal bed into segments and examining each segment separately. An average temperature is assumed for the first segment of the bed for a particular power level and oxygen flow rate; adsorption values (k) for krypton and xenon were determined at this temperature from experimental data; the amounts of the various gaseous isotopes adsorbed in the segment are determined; then the charcoal temperature resulting from beta decay of the various isotopes in this segment was calculated. If the calculated temperature agreed with the assumed temperature then the next segment of the charcoal bed was examined. If the two temperatures did not agree, then a new temperature was assumed and the calculation remade. The composition of the oxygen-rare gas stream was adjusted for decay of the fission gases in the preceding segments of the bed before a new segment was examined. By repeating this procedure over the entire bed a longitudinal temperature profile was developed. In lieu of a thermal conductivity value for charcoal under conditions present in the HRT beds, the value, 0.03 BTU/hr ft^2°F/ft, used by Leland in the design of the HRT beds was utilized (3). The external wall temperature of the charcoal bed was assumed to be 20°C. The following table lists the calculated maximum charcoal temperature at the inlet of the various pipe sizes under equilibrium conditions.

The attached graph displays the complete longitudinal temperature profile for two power levels and oxygen flow rates. As the total oxygen flow increases at a constant power level the critical temperature zone penetrates deeper into the charcoal bed. At a 10 MW power level with 2 liters/min oxygen flow the highest temperature is present at the inlet to the 6 inch diameter pipe. At the same power level with 0.5 liter/min oxygen flow the highest temperature is found in the 0.5 inch diameter pipe.

It should be noted that these charcoal temperatures were calculated under equilibrium conditions and that these conditions will be realized only after several weeks or months of reactor operation at constant power and oxygen flow rate. For this reason the charcoal temperatures measured by the thermocouples in the charcoal should be used to determine the maximum oxygen flow that can be tolerated under non-equilibrium conditions. These calculations will be useful in indicating where the critical temperature zone exists in the charcoal beds under various conditions of reactor operation.

Calculated Charcoal Temperatures for Two HRT Beds in Parallel with External Wall Temperatures of 20°C

Reactor Power (MW)	Total O_2 Flow from Reactor (Liters/min)	Charcoal Temperature at Inlet of Various Pipes(°C) 0.5 in.		1 in.		2 in.		6 in.	
		Ta*	Tm*	Ta	Tm	Ta	Tm	Ta	Tm
5	2	41	62	46	72	54	88	82	144
10	0.5	59	98	47	74	40	60	20	20
10	2	50	80	61	102	79	138	111	202

*Ta is the weighted average of the radial temperature profile of charcoal at inlet of pipe; Tm is the maximum temperature at center of charcoal mass at inlet of pipe.

IV. Conclusions

Based on these experiments and calculations of the expected temperatures, it appears that the probability of ignition of the charcoal in the HRT beds is very low, provided the reactor is operating at a power level not exceeding 10 MW with an accompanying gas flow to the beds not exceeding 2 liters/min.

If, by a combination of circumstances, the charcoal beds should ignite and oxygen flow is continued, temperatures along the axis of the beds in the neighborhood of 1000°C would be expected. The temperature of the stainless steel pipe containing the charcoal will be below 100°C because of water cooling. The combustion rate of charcoal, after ignition occurs, depends upon the supply of oxygen. Reducing the available oxygen supply reduces the combustion rate. Complete stoppage of oxygen flow reduces the combustion rate sharply in a very short time. Charcoal temperatures dropped very rapidly in the experiments upon stopping the oxygen flow, however resumption of oxygen flow caused the charcoal to burn again unless a cooling period long enough to allow the charcoal temperature to drop below 200°C had been provided.

The downstream propagation rate of the burning front is slow enough to allow detection and corrective action to be taken before serious damage has occurred in the bed. Adsorbed fission gases desorbed by the combustion of the charcoal will be readsorbed in later sections of the charcoal bed so that no sudden release of activity into the atmosphere is expected.

If one of the HRT charcoal beds should ignite, it will be possible to extinguish the fire by stopping oxygen flow in that particular bed and allowing a sufficient cooling period. If should not be necessary to seal the exit of the bed. Operation of the reactor could be continued by diversion of the oxygen stream to an alternate charcoal bed.

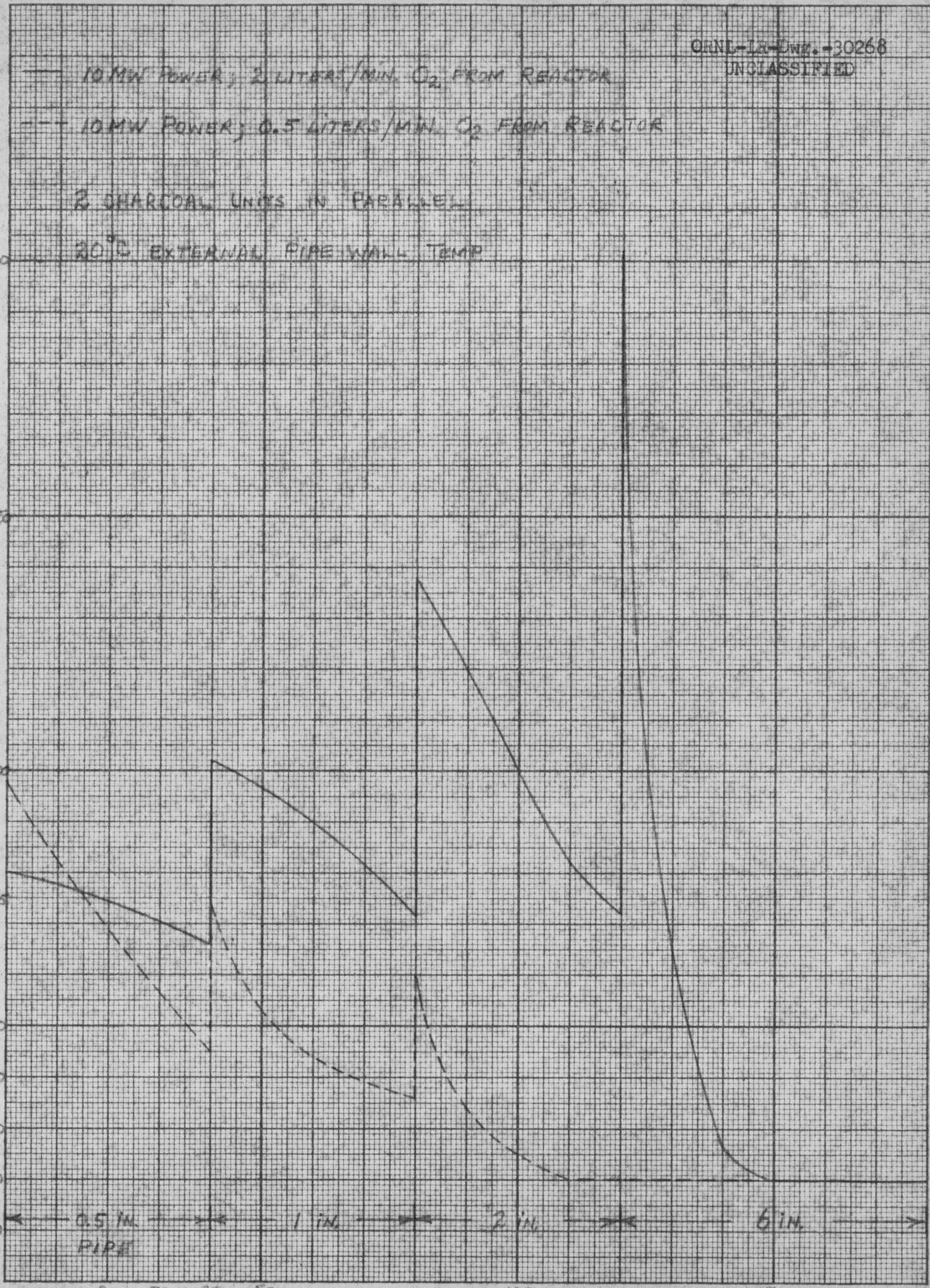
References

1. R. E. Adams and W. E. Browning, "Fission Gas Holdup Tests on HRT Charcoal Beds", ORNL-CF-58-4-14, April 2, 1958.

2. J. E. Bigelow, et al., "Action of Oxygen on Activated Charcoal", KT-107, June 29, 1957.

3. T. W. Leland, "Design of Charcoal Adsorbers for the HRT", ORNL-CF-55-9-12.

LONGITUDINAL MAXIMUM TEMPERATURE PROFILE - HRT CHARCOAL BED



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